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An Investigation on the Impact Noise of a Six-Bar Linkage Mechanical Press

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Abstract

Conventional mechanical press consisted of crack and slider is one of the most commonly used for stamping. But it cannot satisfy deep drawing operations, in which long dwelling time in the BDC is desirable to avoid crack or wrinkle. This motives the design of a six-bar linkage for the mechanical press. However, the working noise is introduced by the new mechanism. This paper presents a systematics study on the noise of the mechanical press. A combination of noise signature analysis, rigid body dynamics analysis and finite element method (FEM) are adopted to investigate the root cause of the noise. It is found that the noise is caused by the collation of the gears. Finally, an improved design is then proposed and some suggestions are given to reduce the noise.

Keywords: Six-bar mechanical press, Signature analysis, Impact noise, Finite element method (FEM)

1. Introduction

Conventional mechanical press consisted of crack and slider is one of the most commonly used for stamping. Its trajectory is not controllable at the bottom dead centre (BDC), and hence it cannot satisfy the diverse needs [1]. For example, long dwelling time in the BDC is desirable to avoid crack or wrinkle for deep drawing operations [2]. This motives the design of the five-, six-, nine- bar linkage for the

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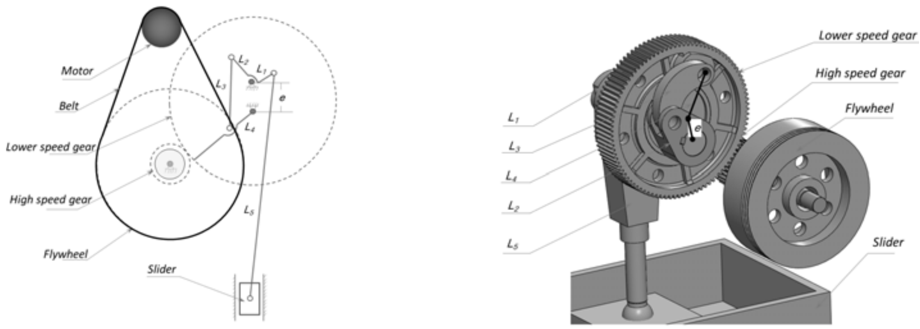
mechanical press [3, 4]. In general, in the design of a mechanical metal forming press, designers concern mostly the kinematics [5]. Few have studied the dynamics of the press, though it is very important its performance [6]. When a commercial press is designed and built, it's necessary to investigate its performance and make continuous improvements.

In this research, a six-bar linkage (including a four-bar linkage and a crank-slider mechanism) has been adopted to build a commercial mechanical press with the capability of max loading of 300ton. Design engineers had carefully checked the kinematics of the press and the manufacturing and assemblies were done within the design specification and therefore the press works fine. Though, the press generates loud noise with and without loading. The sound intensity is higher than 90*db*, which causes various concerns, such as the reliability of the machine and the safety of the operator.

The mechanism of the driveline is illustrated in Fig. 1 (a), and its CAD model is shown in Figure 1(b). It consists of seven parts: a motor (not shown in the figure) that connects to the flywheel through the high speed shaft, a reduction gear set (which includes the high speed gear and the low speed gear), a coupler that controls the engagement of the gear set and the crank, a crank-slider mechanism, and a four bar mechanism that connects to the slider. Among them, the four bar mechanism is the key as it doctrines the dynamic performance of the press.



L_1=45*mm* L_2= 165*mm* L_3=208 *mm* L_4= 260*mm* L_5=800~10000*mm* $e_=$ 80*mm*

Fig. 1. (a) Illustration of the six-bar linkage mechanism; (b) the physical model of the mechanism

This paper aims to find the root cause(s) of the noise. The presented research will investigate the noise from various aspects and provide improvement solutions. The rest of this paper is organized as follows. The signature analysis of noise is presented in Section 2. In Section 3, the dynamics of the system is studied by rigid-body dynamics analysis and FEM. In Section 4, an improved design is proposed to reduce the impact noise. Finally, conclusions are given in Section 5.

2. Signature analysis of noise signal

2.1. Experimental setup

As mentioned earlier, the noise is the major concern of the design. The first step is to analyze the noise signal. The sound signal was measured using a microphone placed closely to the press. Figure 2 shows the experimental setup, the main apparatuses include a microphone (Manufacturer: Brüel & Kjær, Model: Type 4191), a signal amplifier (Behringer, Model: XENYX802), a signal acquisition system (a sound card) and a PC computer. The frequency range of the microphone is 3.15 *Hz* ~ 40 *KHz*.

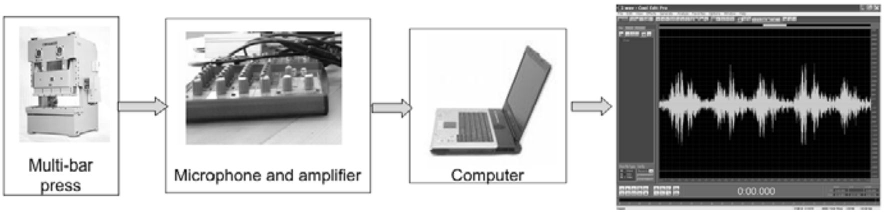


Fig. 2. Experimental Setup

2.2. Noise signal and signature analysis

During the experiment, the operating speed of the press is set at 100 stroke per minute (SPM) (thus, the operating frequency is 1.67 *Hz*), no loading was applied and the sampling frequency was 48 KHz. Fig. 3(a) shows a typical noise signal. Fig. 3(b) is a zoom-in of three cycles, from which it is seen that each period consists of two large peaks, A and B.

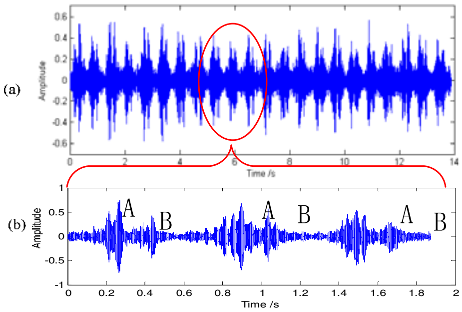


Fig.3. A typical noise signal

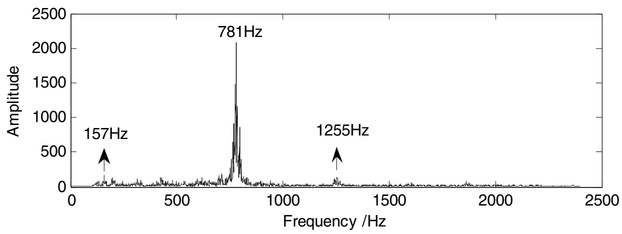


Fig. 4. Spectrum of the noise signal

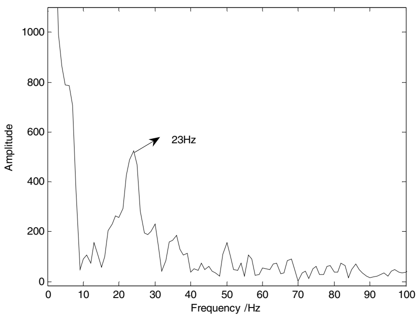


Fig. 5. Envelope spectrum of the noise signal

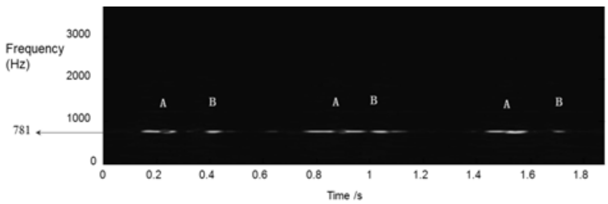


Fig. 6. Energy-time-frequency spectrum of the noise signal

Fig. 4 shows the FFT spectrum of the signal in Fig. 3. From the figure, it is seen that the noise signal has three main components at 157 *Hz*, 781 *Hz* and 1,255 *Hz* respectively. The component at 157 *Hz* is correspondent to the gear meshing frequency and its energy is rather small. The component at the 781 *Hz* has the largest amplitude and is responsible for the noise. It will be the focus of the study.

Fig. 5 shows the envelope spectrum. From the figure, it is seen that the main frequency is at 23 *Hz*, which is the occurring frequency of the peaks. This indicates that the noise is caused by a series of impacts in each working cycle. Fig. 6 shows the time-frequency spectrum of the signal. From the figure, it is seen that along the 781 *Hz* a series of peaks appear, and their amplitudes changes from time to time. However, there are mainly two high peak (corresponding to Peaks A and B in Fig. 3) appeared in each period. Moreover, the amplitude of Peak A is larger that of Peak B.

Based on the study above, it can be seen that (a) there are two large impacts in each cycle corresponding to A and B respectively, (b) the main frequency of the noise is 780 *Hz*; and (c) the impact frequency is 23 *Hz*. It is necessary to analyze the dynamics of the drive system to find the root cause of the noise.

3. Dynamics analysis

3.1. Impact force analysis

To investigate the sources of the noise, the dynamic model of the system is necessary for further investigation of mechanical, which may reflect real working conditions, should be constructed for an accurate loading analysis. In this research, the dynamic analysis of the press is carried using a commercial software system RecurDyn®. All joint force between the linkages are obtained by this simulation, among which the contact force between the gears is attracted our interesting. Fig. 7 shows the contact force (in black) between the gears, and its differentiation (in orange). Examining the differentiation of the force, it is seen that the contact force quickly changes its direction twice, in A and B, when the punch is moving up. This is very likely to create two big shocks. Consequently, a loud noise will be generated.

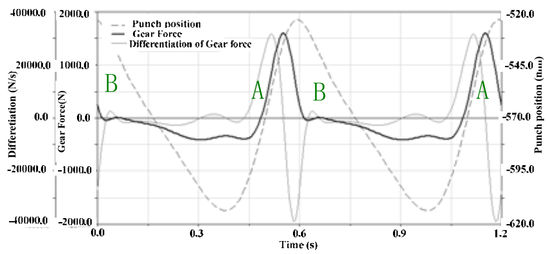


Fig.7. Impact force between the gears

In order to further investigate the frequency components in the noise signal, though, Finite Element Analysis (FEA) is necessary.

3.2. Natural frequencies of the mechanical components

It's well known that the vibration is usually caused by the vibration of structure, and therefore, it's necessary to find the natural frequency of the structure. The analytical method can be used to find the natural frequency. However, it is not precise because of the assumptions. In practical, FEA is a variable method to find the precisely solution of differential equations for verifying the vibration of a structure. There is some commercial software for FEA such as Abaqus®, Ansys®, Nastran®, and *etc*[7, 8]. In this research, we used Abaqus® to find the natural frequencies of the mechanical components as shown in Table 1.

Also, the first mode shape of the high speed shaft is torsion, which is in the same direction of the torque. It is believed that this mode is responsible for repetitive frequency of 23 *Hz*. And the fourth natural frequency of high speed gear and the second natural of low speed gear are close to the mainly frequency of the noise. Moreover, the corresponding mode shape is bending of the gear tooth. Therefore, the gear tooth should be further investigated.

Fig. 8(a) shows the FEA model of the low speed gear. The loading is applied to one of the teeth. The applied loading is a normalized force of 1 unit, in the frequency range from 1 *Hz* to 1,500 *Hz*. Fig. 8(b) shows results of the frequency response. From the figure, it is seen that the gear has three main frequencies at 480*Hz*, 740*Hz*, and 1,350 *Hz* respectively. The largest frequency component is at 740 *Hz*. It is believe that this frequency is responsible for the loud noise. The discrepancies between the FEA frequency (740 *Hz*) and actual noise frequency (780 *Hz*) may be attributed to the simplification of the FEA model. In conclusions, we believe the loud noise is generated by the collision of the gears, and the noise can be reduced by eliminating of the gear clearance.

Table 1. Modal frequencies of the main components of the press (*Hz*)

Mode	1st	2nd	3rd	4th	5th	6th
High speed shaft	24.2	29.7	54.8	285.3	581.0	1035.4
High speed gear	67.3	360.5	466.1	753.0	892.9	1189.0
Low speed gear	593.1	619.0	1147.8	1205.3	1278.0	1477.0
Upper linkage	67.0	74.7	80.5	102.6	185.2	282.4

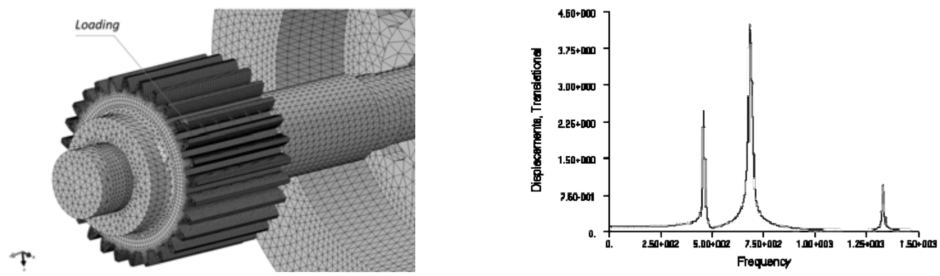


Fig. 8 (a) FEM model of the gear pinion (b) frequency response

4. An improved design

Based on the analysis result presented earlier, the length of the linkages should not be change as to keep the trajectory of the design. Also, the inertia of the flywheel and the stiffness of the high speed shaft *etc.*, can also be fine-tuned to reduce the noise. However, these solution is not effective because of the mechanical components has small room for improving the design due to the strength constraints. It's an option to improve the design by eliminating the clearance between the gears. The proposed design is shown in Fig. 9. There are two gears mounted on the high speed shaft to eliminate the gear clearance.

In this design, two set of gear pair are utilized and one spiral spring will mounted between the gears to eliminate the gear clearance. The first set of gear pair will transmit the torque to the crank shaft for the case of the torque is in clockwise direction. When the torque changes its direction, the second set of gear pair works. Therefore, it's believed that the design will reduce the noise effectively. However, the dynamics analysis is needed for the new design model in the future.

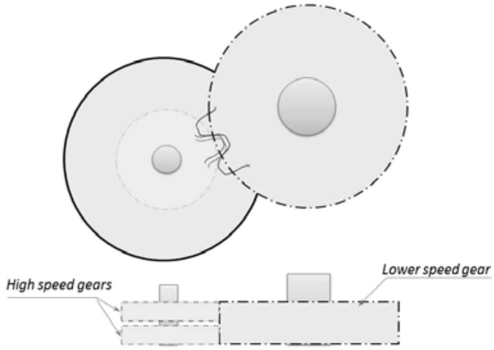


Fig. 9. An improved design of the gear pair for eliminating the gear clearance

5. Conclusions

This paper presents a study on the noise of a six-bar mechanical press. Based on the discussions above, following conclusions can be drawn:

- The mechanical noise of the press contains a number of components corresponding to the natural frequencies of various components of the press. The noise is generated when the impact occurs.
- The impact is a result of the four bar mechanism that generates variable speed during the operation. The variable speed generates variable force, causing the gears impact on each other. It's an option to avoid the clearance between the gear pairs to reduce the noise.
- The combination of the signature analysis, mechanical dynamics analysis and FEM is effective method to analyze the root cause of machine faults. In addition to the application presented above, it can be used for many other applications that involve mechanical motion.

Acknowledgements

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